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TECHNICAL NOTE

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EXPERIMENTAL PANEL FLUTTER RESULTS FOR SOME FLAT AND CURVED TITANIUM SKIN PANELS AT SUPERSONIC SPEEDS

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SUMMARY

The results of tests at Mach numbers from 1.72 to 2.62 on panels having a thickness from 0.015 to 0.045 inch, length-width ratio from 0.36 to 2.76, and radius-thickness ratio from 600 to infinity are presented. These results indicate a strong influence of differential pressure, which caused buckling, on the flutter mode and on the dynamic pressure at flutter for the curved panels. Results for both the flat and curved panels fall within an extrapolation of an existing experimental panel flutter boundary.

end

INTRODUCTION

Panel flutter has become an increasingly important design consideration for supersonic vehicles. Theoretical methods have not advanced enough to determine reliable panel flutter boundaries, and experimental results are generally used in design work. Minimum weight requirements, new materials, and manufacturing processes have contributed to the complexity of the skin structures, and additional experimental investigations are required for many new vehicles.

In order to supplement available experimental results, an investigation of the flutter characteristics of some low-aspect-ratio flat and curved titanium panels has been conducted in the Langley Unitary Plan wind tunnel. The panels were constructed of 0.050-inch-thick sheets of titanium riveted to essentially rigid members on the four edges with the unsupported section chemically milled in steps to the desired skin thickness. Two panels having a radius of curvature of 48 inches and a radius-thickness ratio of 2,400 and one panel having a radius of curvature of 12 inches and a radius-thickness ratio of 600 were tested. The effect of pressure differential across the panel was also investigated. Tests were conducted over a Mach number range from 1.72 to 2.62 at dynamic pressures up to 2,670 lb/sq ft.

SYMBOLS

E	Young's modulus of elasticity
l	unsupported panel length in streamwise direction, in.
M	Mach number
p	static pressure on panel support face, lb/sq ft
p_c	cavity pressure behind panel, lb/sq ft
Δp	pressure differential across panel, $p_c - p$, lb/sq ft
q	dynamic pressure, lb/sq ft
t	skin thickness, in.
w	unsupported panel width, perpendicular to airstream, in.

$\beta = \sqrt{M^2 - 1}$

APPARATUS

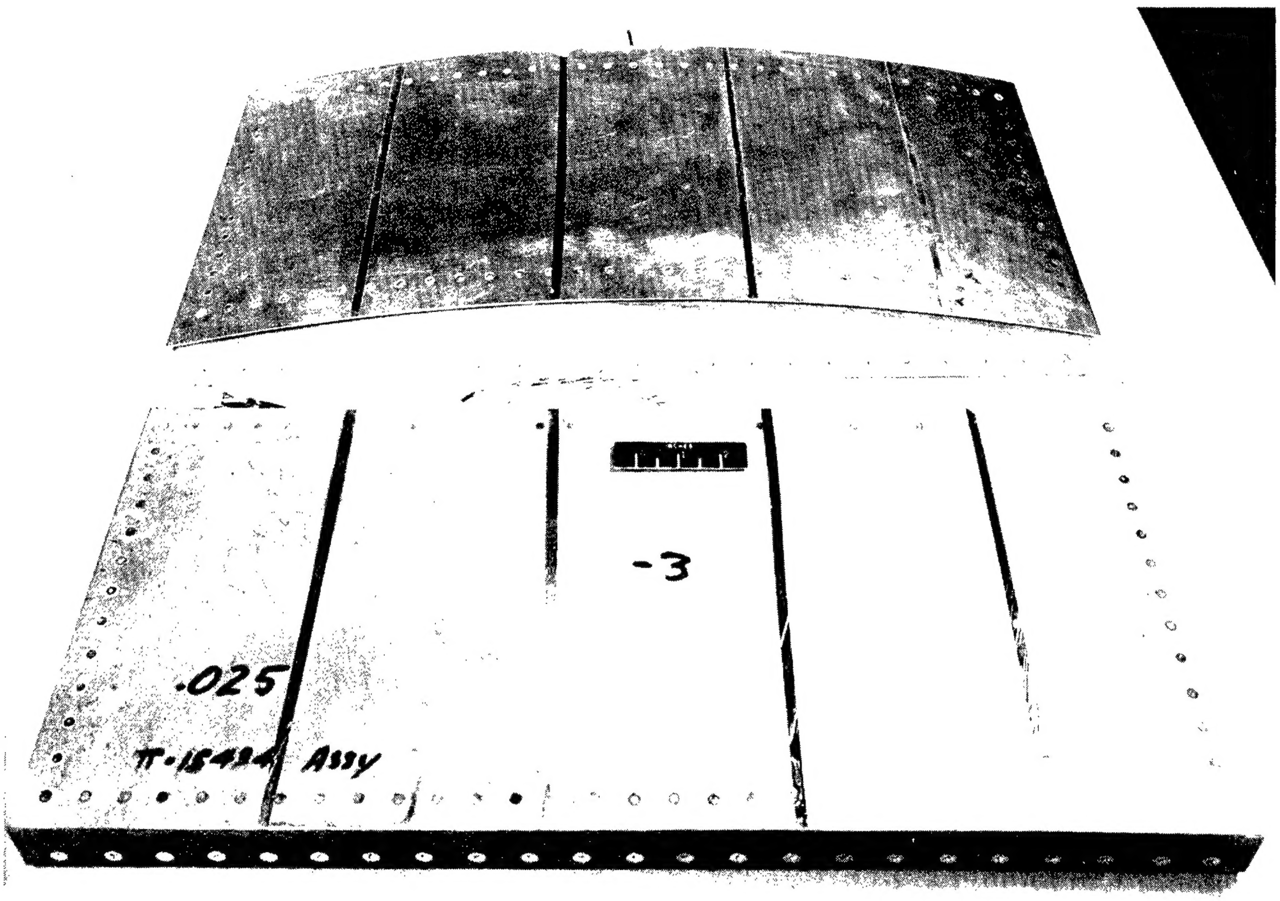
Wind Tunnel and Panel Support

Tests were conducted in the low Mach number test section of the Langley Unitary Plan wind tunnel, a variable-pressure, continuous-flow tunnel. The test section is 4 feet square and approximately 7 feet in length. The nozzle leading to the test section is of the asymmetric sliding-block type, and Mach number may be varied from 1.6 to 2.9 without tunnel shutdown.

The panel support system for flutter tests consists of a vertical splitter plate extending from floor to ceiling of the test section. In order to avoid the effects of the tunnel wall boundary layer, the flat surface or test side of the splitter plate is located about 15 inches from the tunnel side wall. Figure 1 includes photographs of the panel support installed in the test section. The face of the test-section door on which the support is mounted is dished out, and this in combination with a 1° angle of attack of the flat surface of the splitter plate compensates for the presence of the splitter plate in the airstream and, thus, prevents tunnel choking.

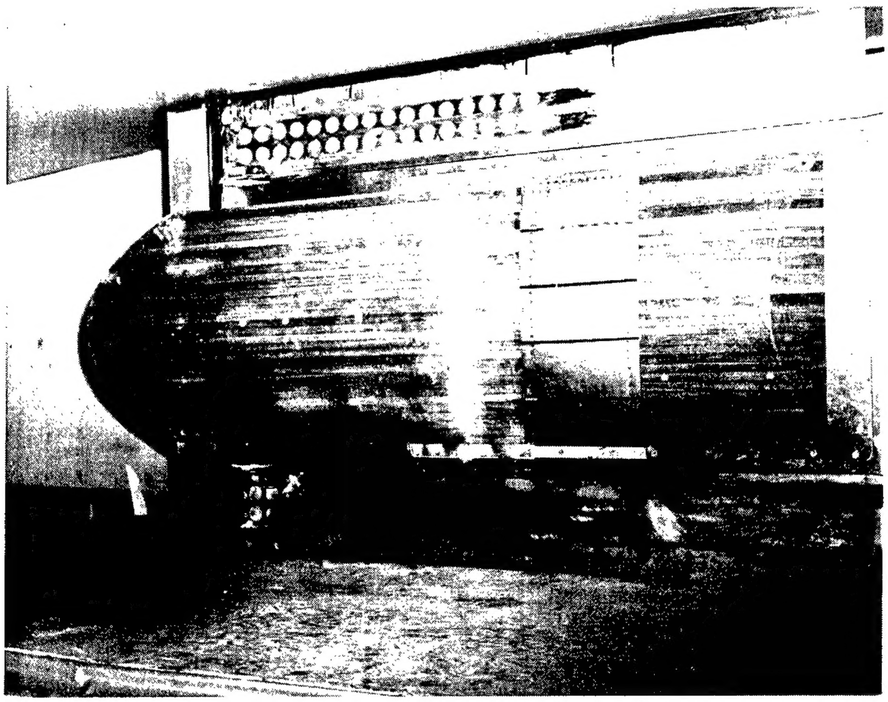
A static-pressure survey over the face of the splitter plate indicated that the Mach number was reduced by 0.04 over the panel because of the 1° angle of attack of the splitter plate. This reduction was indicated for both the flat

splitter plate configuration and the configuration with a curved fairing in place, and all Mach numbers quoted herein are so adjusted. The pressure survey indicated that a maximum deviation over the test panel surface of 3 percent of the free-stream static pressure occurred at a Mach number of 1.72 and diminished to a value of about 1 percent of the free-stream static pressure at a Mach number of 2.11.



(a) Typical flat and curved panels. L-61-1339

Figure 1.- Model photographs.



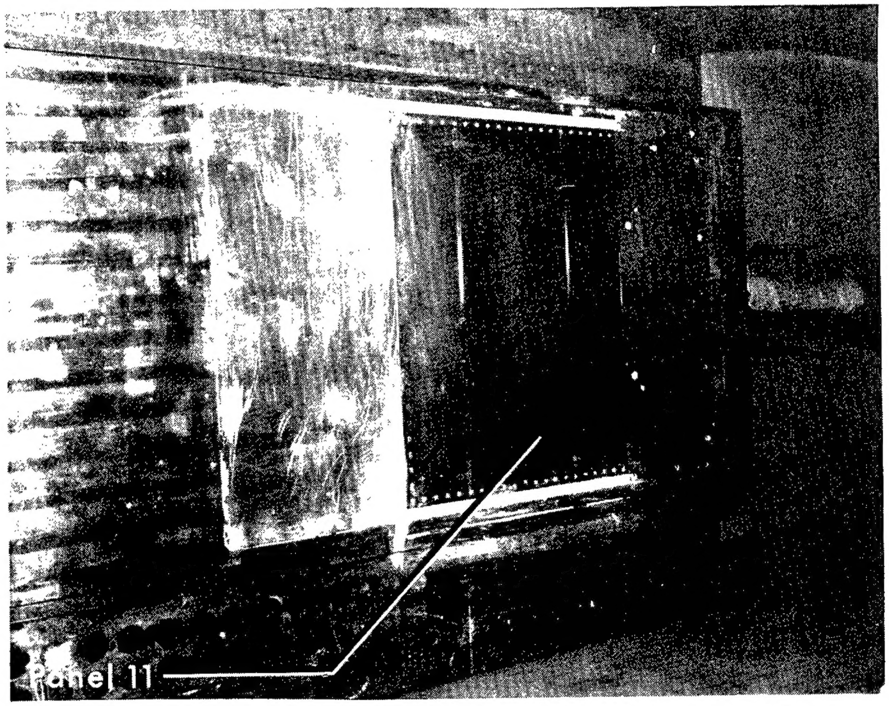
(b) Typical curved-panel installation. L-60-8612

Figure 1.- Continued.

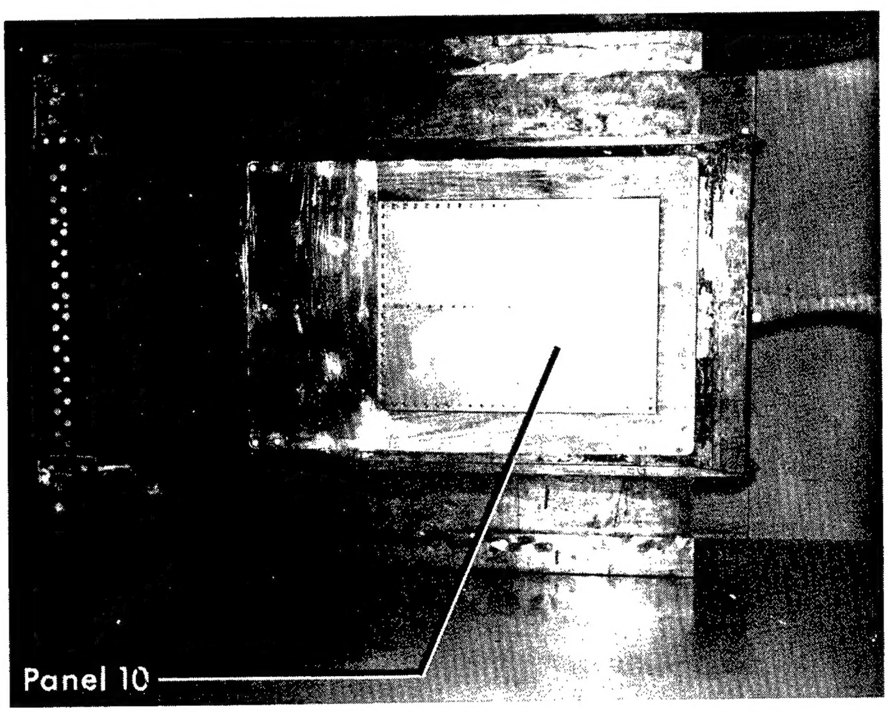
Panels and Instrumentation

Panel geometric characteristics are presented in table I, and pretest vibration data with sketches of the node line locations are presented in table II. It should be noted that the node line location and frequencies are in some cases different than are ordinarily expected for a simple panel when only the structural restraints are considered. For example, the sequence of panels 1 to 3 represents a progressive decrease in panel thickness. It was expected that the frequency for a given mode of vibration would decrease with this sequence in an orderly manner, but this did not happen. The variation of frequency with mode shape for an individual panel was also unusual, in most cases. The behavior of these natural modes is thought to be caused primarily by cavity effects and secondarily by construction inaccuracies.

Photographs of the panels and tunnel installation are presented in figure 1, and sketches of the test panel construction are presented in figure 2. The panels were constructed of 0.050-inch-thick titanium sheets riveted on the four edges to steel angles. The unsupported portion of the sheets was chemically milled in two steps to lesser skin thicknesses as indicated in table I and as shown in figure 2. The angles supporting the skin were bolted to another steel angle which when mounted in the splitter plate formed a sealed box about 1.8 inches deep with the skin surface of the flat panels flush with the face of the splitter plate.



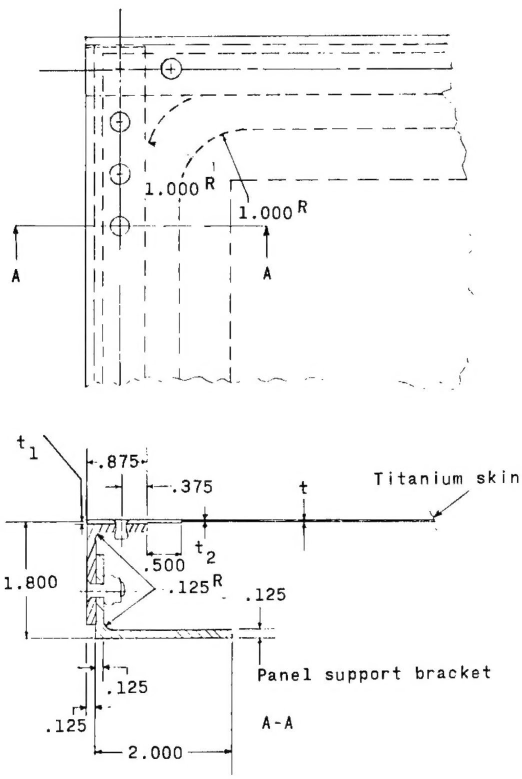
L-61-5834.1



(c) Stiffened-panel installation. L-61-5835.1

Figure 1.- Concluded.

The curved panels were constructed in a similar manner and curved wooden fairings were added to the face of the splitter plate as shown in the photograph in figure 1(b). The projected width of the 48-inch-radius curved panels was about 22 inches and that of the 12-inch-radius panel was about 16 inches.



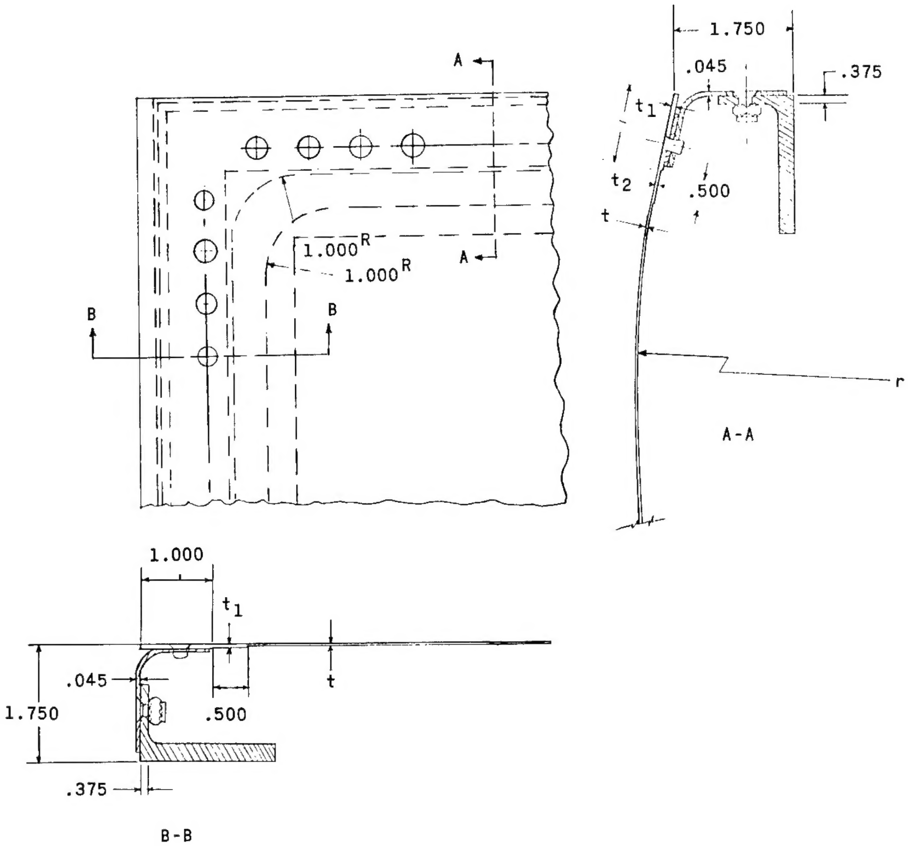
(a) Flat-panel construction.

Figure 2.- Test panel details. All dimensions in inches.

Each panel was instrumented with three strain gages and two variable-reluctance deflection pickups. Four of these five channels of information were selected for each run and recorded continuously on a magnetic tape recorder. Pressure in the sealed compartment behind the panels was remotely controlled by a pressure regulator and measured by means of a differential pressure gage which measured the difference between the cavity pressure and the static pressure on the panel support face. Motion pictures were taken during flutter at 1,000 frames per second to study the flutter modes and to insure that the signals recorded originated in the panels and not from faulty instrumentation.

TEST PROCEDURE

In general, tests were conducted by using the following procedures: Supersonic flow was established at a low dynamic pressure, and the sliding-block nozzle was moved from the optimum starting Mach number position to the desired test Mach number position. Dynamic pressure was then increased in steps or, in some instances, at a slow rate. At each level of dynamic pressure or simultaneously with the slow rate of dynamic-pressure increase, the pressure behind the panel was cycled producing pressure differences across the panel within the range of about ±100 lb/sq ft. When flutter occurred, tunnel dynamic pressure and the pressure behind the panel were recorded manually. For the flat panels there was a definite pressure differential, usually near zero, for which the panel fluttered at the lowest dynamic pressure. After an approximate flutter level had been initially established and in order to insure that this minimum value of dynamic pressure was obtained, the dynamic pressure was increased into the flutter region several times with the pressure differential set at several positive and negative values.

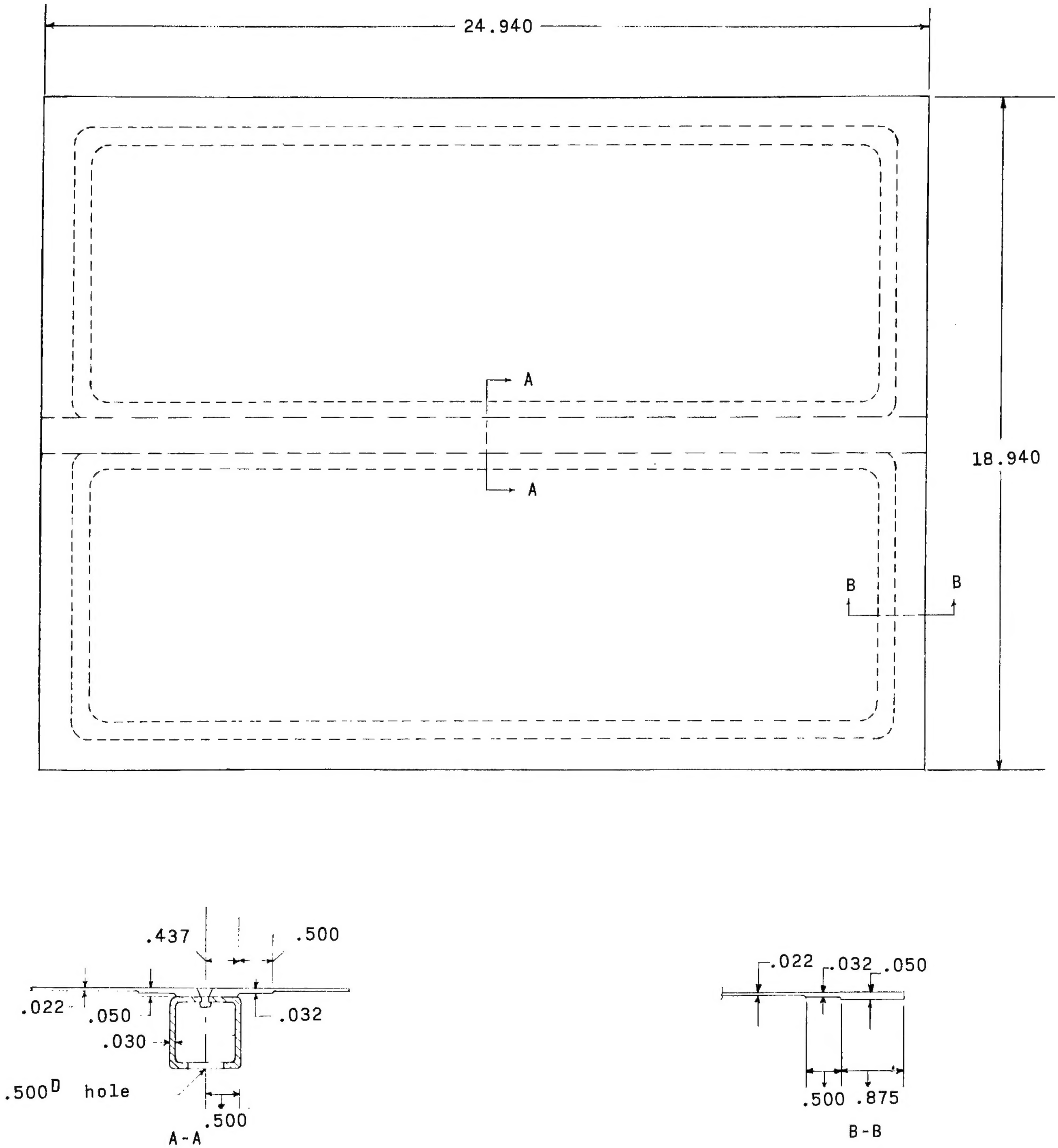


(b) Curved-panel construction details.

Figure 2.- Continued.

DISCUSSION OF RESULTS

The test results are presented in table III. The table includes Mach number, dynamic pressure, pressure differential, a panel flutter parameter $\left(\frac{\beta E}{q}\right)^{1/3}\frac{t}{l}$, and the flutter frequency. The data presented represent points at which flutter started during variation of either dynamic pressure or pressure differential, and the arrows appearing beside these quantities indicate the direction in which the quantity was being varied at flutter inception. Arrows pointing up indicate an increasing value; quantities having no arrows were held constant. Points representing maximum available dynamic pressure for panels which did not flutter are also presented.



(c) Stiffened-panel details (test panels 10 and 11).

Figure 2.- Concluded.

Flat Panels

The results of the flutter tests of panels 1, 2, 3, and 11 are presented in figure 3 in terms of the minimum dynamic pressure at flutter, or the maximum dynamic pressure in cases for which no flutter was obtained, as a function of Mach number. The data do not have a uniform variation with Mach number, but do exhibit the expected trend of increasing dynamic pressure at flutter with increasing panel thickness. The exception to this increase was panel 11 which was visibly buckled when installed in the splitter plate. Evidently, the panel was not severely buckled, since it fluttered at a low dynamic pressure. As described in reference 1, the dynamic pressure at flutter decreases with increasing compressive stress to a minimum; thereafter, an increase in stress increases the flutter dynamic pressure. In reference 1 the minimum dynamic pressure was obtained when the panel was near the critical buckling stress.

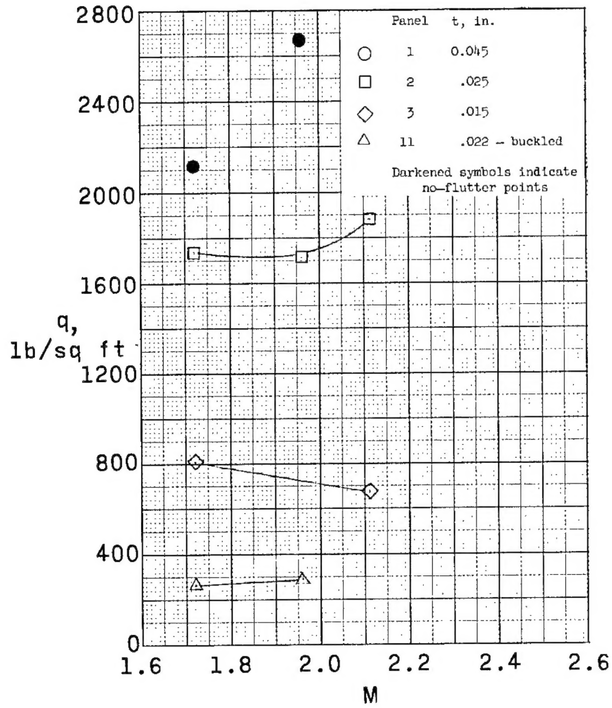


Figure 3.- Effects of skin thickness and buckle condition on minimum flutter dynamic pressure for several flat panels.

Curved Panels

Only one of the curved panels tested (panel 4) fluttered, and the results therefore appear somewhat inconsistent since panels 4 and 5 had the same radius and thickness and differed only by a 1/2-inch-wide, 0.015-inch-thick step increase in thickness along each edge of panel 5. Panel 5 was tested to the tunnel dynamic pressure limit of 2,625 lb/sq ft and did not flutter. The results for panel 4 at a Mach number of 1.72 are plotted in figure 4 for q as a function of pressure differential. The data are for runs 8 and 12 which were two separate tunnel installations. Only one flutter point was obtained on this panel in the unbuckled condition. This point was at a positive pressure differential of 66 lb/sq ft and a dynamic pressure of 1,599 lb/sq ft. This flutter had a very low amplitude and was not visible to the naked eye and was barely visible in the high-speed motion picture. This behavior is in sharp contrast to the buckled flutter which had amplitudes of about 1/4 inch and was easily visible. The variations in frequencies evident in figure 4 were caused by the different buckle patterns which initially occurred. Buckles having a large area had lower frequencies and higher amplitudes than the buckles having a small area. In some cases, the first buckles which occurred were of small area, and the associated flutter (which began immediately after the buckle formed) was of a higher frequency than the flutter which occurred as the pressure differential decreased and caused the small buckles to merge into larger buckles. For example, the two points in figure 4 at a dynamic

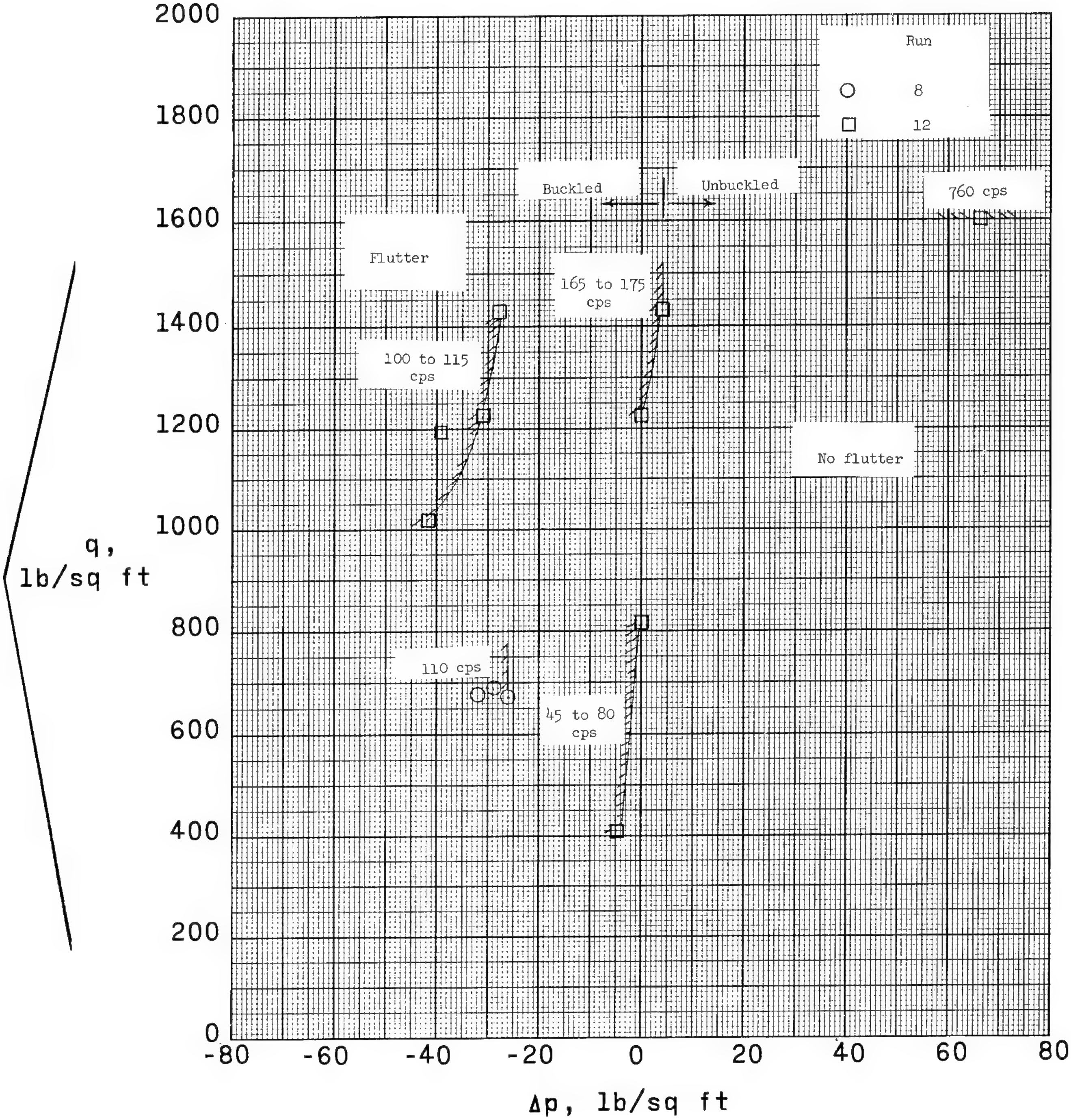


Figure 4.- Flutter boundaries for two tunnel installations of panel 4 at M = 1.72.

pressure of 1,222 lb/sq ft were obtained by holding a constant dynamic pressure and decreasing pressure differential. The panel initially buckled at zero pressure differential and began flutter at a frequency of 165 cps. This flutter continued until the pressure differential reached -31 lb/sq ft; then, the buckle pattern changed and the flutter frequency decreased to 105 cps.

No panels were destroyed during the tests, and an indication of the fatigue life is given by the 0.015-inch-thick panel 3, which fluttered an estimated 2.5 hours with only a slight stretching of the skin.

Comparison of Test Results With Previous Results

Many of the test points obtained were above the minimum flutter dynamic pressure for a particular configuration and are therefore not compared with previously published data. The minimum flutter dynamic pressures for these tests are presented in figure 5 in terms of a panel flutter parameter $\left(\frac{\beta E}{q}\right)^{1/3}\frac{t}{l}$ and compared with the empirical envelope of reference 2. The maximum value of this parameter for each panel, which was encountered during the tests, is presented for all flat panels and for a buckled and unbuckled condition of a curved panel. Most of the data fall well within the envelope.

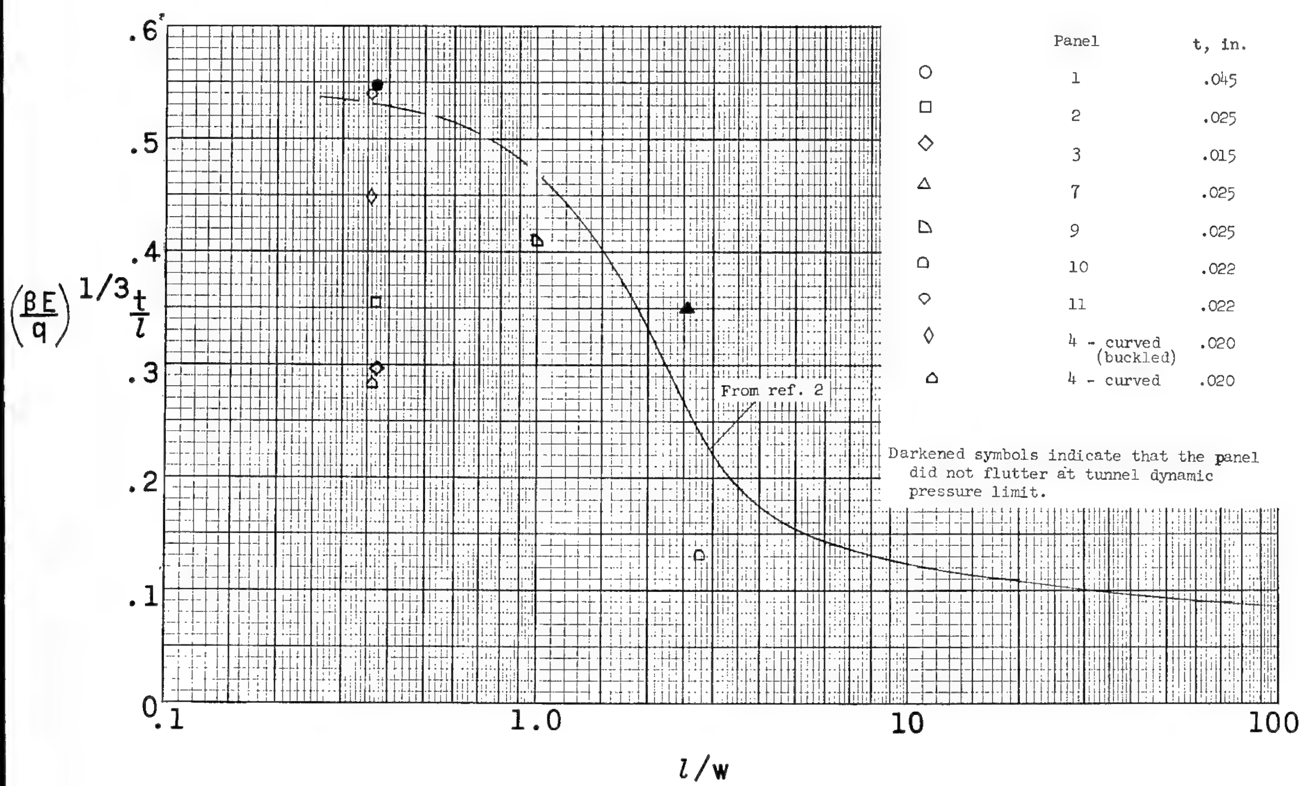


Figure 5.- Comparison of test results with experimental envelope of reference 2.

CONCLUDING REMARKS

The test results show that panel buckling greatly affects the dynamic pressure required for flutter although no degree of buckling was investigated. Results for all flat panels and a curved panel buckled by pressure differential are shown to agree with previous results for flat panels. The flutter characteristics of a curved panel are shown to be highly dependent on the shape the panel assumes when buckled by normal pressure load.

A need for research on the effect of the cavity behind the panel on panel flutter characteristics is indicated by the pretest vibration results.

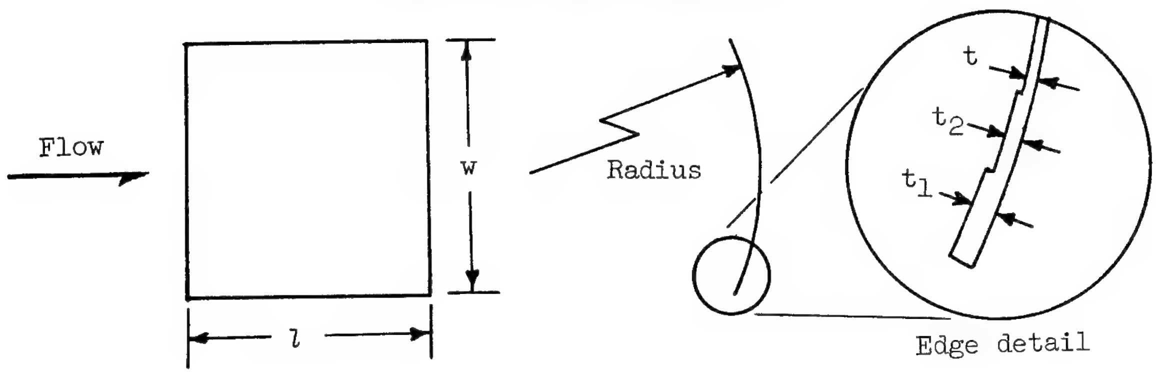
Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., October 22, 1962.

REFERENCES

1. Hess, Robert W., and Gibson, Frederick W.: Experimental Investigation of the Effects of Compressive Stress on the Flutter of a Curved Panel and a Flat Panel at Supersonic Mach Numbers. NASA TN D-1386, 1962.

2. Kordes, Eldon E., Tuovila, Weimer J., and Guy, Lawrence D.: Flutter Research on Skin Panels. NASA TN D-451, 1960.

TABLE I.- PANEL GEOMETRY



Panel	l, in.	w, in.	l/w	Radius, in.	t_1, in.	t_2, in.	t, in.
1	8.25	22.25	0.37		0.045	0.045	0.045
2	8.25	22.25	.37		.050	.035	.025
3	8.25	22.25	.37		.050	.035	.015
4	7.875	22.125	.36	48	.050	.020	.020
5	7.875	22.125	.36	48	.050	.035	.020
6	7.875	16.125	.49	12	.050	.035	.020
7	8.25	3.25	2.54		.050	.035	.025
8	3.25	8.25	.39		.050	.035	.025
9	8.25	8.25	1.00		.050	.035	.025
10	23.25	[a]8.41	2.76		.050	.035	.022
11	[a]8.41	23.25	.36		.050	.035	.022

[a]Panel includes two bays of this dimension separated by stiffener. (See sketch in fig. 2(c).)

TABLE II.- PRETEST VIBRATION DATA

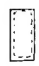
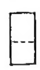
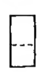
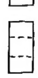
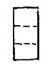
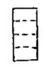
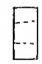
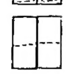
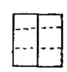
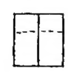
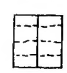
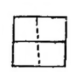
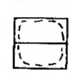
Panel	Δp, lb/sq ft	Natural frequency, cps	Approx. location of node lines
1	0	175	
		200	
		260	
		407	Not determined
		600	Not determined
2	0	146	
		161	
		178	
		191	
		213	
3	0	252	
		150	
		192	Not determined
		500	Not determined
4	-40	76	Not determined
		82	Not determined
		140	Not determined
	0	202	
		230	
		240	
		295	Not determined
		325	Not determined
		400	Not determined
	30	217	
		363	
		295	
		474	Not determined
5	0	230	
		245	
		305	
6	0	475	
		500	
		550	Not determined
7; 8	0	460	Not determined
		650	Not determined
		890	Not determined
9	0	139	Not determined
		203	Not determined
		285	Not determined
		338	Not determined
		393	Not determined
		433	Not determined
10	0	79	
		145	
		219	
		248	
		275	
		303	Not determined
11	0	93	
		130	
		175	

TABLE III.- TEST RESULTS

Panel	Run	Point	Mach number	q, lb/sq ft (a)	Δp, lb/sq ft (a)	$\left(\frac{\beta E}{q}\right)^{1/3}\frac{t}{l}$	Flutter frequency, cps	Comments
1	1	1	1.72	2,114	Vary ±100	0.5564	No flutter	Max. q
	2	2	1.96	2,670	Vary ±100	.5467	No flutter	Max. q
2	3	3	1.72	↑ 888	↑ 42	.4122	No flutter	
	3	4	1.72	↑1,727	↑ 16	.3297	No flutter	
	3	5	1.72	↑1,816	↑ 28	.3248	185	
	3	6	1.72	1,733	24	.3297	185	Min. flutter q
	4	8	1.96	↑1,724	↑ 22	.3515	156	
	4	9	1.96	↓1,700	22	.3600		Flutter stopped
	5	10	2.11	↑1,882	↓-30	.3539	155	
	5	11	2.11	↓1,857	-30	.3539		Flutter stopped
3	6	12	1.72	↑ 806	-11	.2545	60,290	Min. flutter q
	6	13	1.72	814	↑ 37	.2533	60,400	
	6	14	1.72	1,017	↑ 13	.2303	60,320	
	6	15	1.72	1,222	↑ -6	.2230	60	
	6	16	1.72	1,657	↑-19	.2012	60	
	6	17	1.72	1,686	↑ -2	.2000	60	
	7	18	2.11	↑ 670	-18	.2976	No flutter	
	7	19	2.11	↑1,175	↑-12	.2473	Flutter	Frequency not determined
	7	20	2.11	↓1,007	↑ 12	.2606	Flutter	Frequency not determined
	7	21	2.11	838	↑100	.2776	60 and 760	
	7	22	2.11	670	-17	.2970	60 and 155	Min. flutter q
	7	23	2.11	838	↑ 2	.2776	Flutter	Frequency not determined
	7	24	2.11	1,007	↑ 1	.2727	60 and 750	
	7	25	2.11	1,175	↑ 10	.2473	Flutter	Frequency not determined
	7	26	2.11	1,343	↑-31	.2315	Flutter	Frequency not determined
	7	27	2.11	1,016	↑-25	.7606	60 and 175	
4	8	28	1.72	↑ 677	↓-32	.3784	Flutter	Frequency not determined
	8	29	1.72	683	↓-20	.3771		Flutter stopped
	8	30	1.72	685	↓-29	.3759	110	
	8	31	1.72	671	↓-26	.3810	117	
	9	32	1.96	↑ 678	↓-21	.3975	120	
	9	33	1.96	710	↓-16	.3962	120	
	10	34	2.11	↑ 813	↓-19	.3924	115	
	10	35	2.11	↓ 589	-19	.4356		Flutter stopped
	11	36	2.62	↑ 577	↓-45	.4800	120	
	11	37	2.62	581	↓+11	.4787	120 and 245	
	11	---	2.62	312	↓-26	.5892		Flutter stopped
	12	38	1.72	↑ 408	-5	.4483	45	Buckled condition
	12	39	1.72	408	↑ 62	.4483	No flutter	Buckled condition
	12	40	1.72	814	↓ 0	.3276	45 and 78	Buckled condition
	12	41	1.72	1,017	↓-42	.3302	103	Buckled condition
	12	42	1.72	1,193	↓-39	.3137	97	Buckled condition
	12	43	1.72	1,222	↓ 0	.3111	165	Buckled condition
	12	44	1.72	1,222	↓-31	.3111	105	Buckled condition
	12	45	1.72	1,428	↓ 4	.2946	175	Buckled condition
	12	46	1.72	1,428	↓-28	.2946	115	Buckled condition

[a]Arrows pointing up indicate an increasing value; arrows pointing down indicate a decreasing value.

TABLE III.- TEST RESULTS - Concluded

Panel	Run	Point	Mach number	q, lb/sq ft (a)	Δp, lb/sq ft (a)	$\left(\frac{\beta E}{q}\right)^{1/3}\frac{t}{l}$	Flutter frequency, cps	Comments
4	12	47	1.72	↑1,599	66	0.2844	760	Unbuckled
	13	48	2.11	↑ 838	↓-30	.3873	62	Buckled condition
	13	49	2.11	1,007	↓-23	.3644	72	Buckled condition
	13	50	2.11	1,175	↓-34	.3467	78	Buckled condition
	13	51	2.11	1,343	↓-21	.3314	88	Buckled condition
	13	52	2.11	1,508	↓-22	.3187	89	Buckled condition
	13	53	2.11	1,508	↓-25	.3187	83	Buckled condition
	13	54	2.11	1,677	↓-23	.3073	100	Buckled condition
	13	55	2.11	1,845	↓-24	.2971	91	Buckled condition
5	14	56	1.96	2,625	Vary ±100	.2565	No flutter	Max. q
6	15	57	1.72	2,100	Vary ±100	.2590	No flutter	Max. q
	16	58	1.96	2,625	Vary ±100	.2552	No flutter	Max. q
7	17	59	1.72	1,295	Vary ±100	.3635	No flutter	Max. q
	18	60	1.96	1,745	Vary ±100	.3505	No flutter	Max. q
8	19	61	1.96	1,740	Vary ±100	.8876	No flutter	Max. q
9	20	62	1.96	↑1,098	↓-60	.4086	230	
	20	63	1.96	1,098	↑ 0	.4086	No flutter	
	21	64	1.72	900	-50	.4103	240	Min. flutter q; intermittent flutter
	21	65	1.72	1,010	↓-50	.3947	240	
	21	66	1.72	1,050	↓-50	.3898	240	
	21	67	1.72	1,110	↓-50	.3827	240	
	21	68	1.72	1,180	↓-50	.3727	240	
	21	69	1.72	1,445	↓-50	.3504	240	
10	22	70	1.96	↑ 915	0	.1322	104	Min. flutter q
	22	71	1.96	1,025	↑ -6	.1278	112	
	22	72	1.96	1,097	↑ -4	.1252	112 and 220	
	22	73	1.96	1,097	↑ -2	.1252	280	
	22	74	1.96	1,098	↑-10	.1252	105	
	23	75	1.72	↑ 857	0	.1275	280	Min. flutter q
	23	76	1.72	877	↑ -5	.1265	280	
	23	77	1.72	877	↑ -5	.1265	125	
	23	78	1.72	877	↑-15	.1265	150	
11	24	79	1.72	↑ 297	0	.5030	159	Panel initially buckled
	24	80	1.72	↑ 270	0	.5190	159	Min. flutter q
	25	81	1.96	↑ 292	0	.5382	145	Min. flutter q
	25	82	1.96	↑ 296	0	.5382	140	

[a]Arrows pointing up indicate an increasing value; arrows pointing down indicate a decreasing value.

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NASA TN D-1600
National Aeronautics and Space Administration.
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